Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	IB Docket No. 95-91
	)	GEN Docket No. 90-357
Establishment of Rules and Policies for the	)	RM No. 8610
Digital Audio Radio Satellite Service in the	)	PP-24
2310 - 2360 MHz Frequency Band	)	PP-86
	)	PP-87

COMMENTS OF THE CONSUMER ELECTRONICS MANUFACTURERS ASSOCIATION

I. INTRODUCTION AND BACKGROUND

The Consumer Electronics Manufacturers Association ("CEMA")[1/] respectfully submits the following Comments in response to the Federal Communications Commission's ("Commission" or "FCC"), *Further Notice of Proposed Rule Making* in the above-captioned proceeding.[2/]

By way of background, on March 3, 1997 the Commission issued its *Report and Order* outlining a plan to license satellite Digital Audio Radio Service ("DARS").[3/] The Commission's *Report and Order* rejected CEMA's request to consider spectrum alternatives, and instead licensed two S-band satellite-based DARS systems. CEMA's request was based upon test findings indicating

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[1/] CEMA represents the consumer electronics industry including manufacturers of radios, televisions, and compact disk players and digital and analog recorders. Accordingly, CEMA's membership includes most major manufacturers of consumer electronics products as well as smaller companies that design, produce, distribute and service consumer electronics products.

[2/] *See* Establishment of Rules and Policies for the Digital Audio Radio Satellite Service in the 2310-2360 MHz Frequency Band, *Report and Order Memorandum Opinion and Order and Further Notice of Proposed Rulemaking*, IB Docket No. 95-91, GEN Docket No. 90-357, RM No. 8610, PP-24, PP-86, PP-87 (released March 3, 1997).

[3/] *Id.*

that S-band DARS systems suffer from unacceptable signal blockage rates, require a substantial number of "gap filling" transmitters, and otherwise generally deliver service of poor quality.[4/] Nevertheless, the Commission promulgated final rules licensing satellite DARS systems in the S-band. Although the Commission adopted limited satellite construction milestones, the FCC failed to impose upon DARS licensees any substantial coverage or service performance requirements. Because of the inherent characteristics of the S-band, however, CEMA remains concerned that -- in the absence of specific requirements -- the DARS licensees will not choose to incur the significant build-out costs associated with provisioning of seamless, uninterrupted service to urban and mobile end-users. Accordingly, on March 27, 1997 CEMA filed a Petition for Reconsideration of the Commission's *Report and Order* in this matter.[5/] Specifically, CEMA urged the Commission to adopt detailed DARS coverage, quality and build-out requirements necessary to ensure that valuable DARS frequencies are not used solely to provide a niche service limited to users located primarily in rural or fixed locations.

In the Commission's *Further Notice of Proposed Rulemaking*, the FCC seeks comment regarding the utilization and operation of terrestrial gap-filling repeaters. In response to the FCC's request, and as further evidence of its genuine commitment to the commercial viability of satellite DARS, CEMA submits the attached report entitled "Analysis of the technical merits of terrestrial gap

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4/ *See Ex Parte* Submission entitled the Consumer Electronics Manufacturers Association Vision for Digital Audio Radio Services (filed January 30, 1997); *See also, Ex Parte* filing entitled Report of the Field Test Task Group; Field Test Data Presentation (filed January 30, 1997).

5/ Consumer Electronics Manufacturers Association, Petition for Reconsideration, IB Docket No. 95-91, Establishment of the Rules and Policies for the Digital Audio Radio Satellite Service in the 2310-2360 MHz Frequency Band, March 27, 1997 ("CEMA Petition for Reconsideration").

fillers supplementing DAR satellite broadcasting in the L-band and S-band frequency range" prepared for CEMA by the Communications Research Centre Bureau of Radio Broadcast Technologies Research ("CRC Report"). *See* Exhibit 1. As outlined below, the CRC Report provides independent confirmation that the deployment of a significant number of terrestrial gap-fillers is necessary if S-band DARS systems are to realistically provide reasonable service to either urban or mobile users. Furthermore, the CRC Report provides additional support for CEMA's conclusion that satellite DARS licensees operating in the S-band must compensate for significant propagation deficiencies in order to provide acceptable service. In light of the weight of both CEMA's earlier test findings and the attached CRC Report, CEMA urges the Commission to adopt rules governing not only the build-out of terrestrial gap-fillers, but, more generally, the overall coverage, quality and performance requirements of the satellite DARS licensees. Moreover, CEMA believes that the attached CRC Report will be of significant value to both the licensees and the Commission as each considers both the design and regulation of a viable commercial DARS service and an associated network of terrestrial gap-fillers.

II. DISCUSSION

A. S-band Propagation Characteristics Necessitate that Satellite DARS Licensees Rely Upon a Substantial Network of Terrestrial Transmitters in Order to Deliver the Promised, Seamless, CD-Quality Service

Both the Commission and the American public expect that satellite DARS will provide "continuous nationwide radio programming with compact disc (CD) quality sound."[6/] Moreover, it was anticipated that motorists would "be able to tune in to one of many satellite DARS

6/ *See, e.g.* Notice, FCC DARS Auction: Satellite CD Radio, Inc. and American Mobile Radio Corp. High Bidders for Two Nationwide Licenses, 1997 WL 157052 (April 2, 1997).

channels . . . *without interruption or fading* as they travel across the United States."[7]

The Commission presumes, and the satellite DARS licensees apparently accept, the need for terrestrial gap-fillers to supplement the direct satellite signal when it suffers impairments due to blockage by terrain, buildings, foliage and other obstructions. What is now abundantly clear, however, is the overwhelming extent to which the DARS licensees will need to rely upon terrestrial gap-filling transmitters in order to provide the type of seamless service originally promised.

In its previous comments, CEMA detailed the results of the DAR Subcommittee field tests. Those tests demonstrated extensive system failures of the VOA/JPL S-band system, transmitting from a NASA TDRS satellite at a low (23 degrees) elevation angle and received in a vehicle traveling along specified mobile test routes in the San Francisco, California area. On some routes, particularly segments in downtown areas, the signal blockage caused by terrain, buildings and other structures resulted in more than 90% system failures. These system outages could be improved only marginally by a higher elevation angle, higher power and/or diversity satellite transmitters. That other satellite DARS technologies were not tested by the Subcommittee is immaterial, for if the signal does not reach the receive antenna, no coding technology can restore the service. The CRC Report derives the same conclusion -- S-band terrestrial gap fillers are required, in a far higher density, to restore service in mobile environments.[8]

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[7] *See* Establishment of Rules and Policies for the Digital Audio Radio Satellite Service in the 2310-2360 MHz Frequency Band, *Report and Order Memorandum Opinion and Order and Further Notice of Proposed Rulemaking*, IB Docket No. 95-91, GEN Docket No. 90-357, RM No. 8610, PP-24, PP-86, PP-87 at 1 (released March 3, 1997) (emphasis added).

[8] *See* CRC Report at § 5.2.2.

The CRC Report indicates, for example, that a network of as many as **85 omnidirectional** terrestrial gap-fillers would be required to restore S-band service **to an area 30km by 50km.**[9] This density would likely be required in each urban area within the satellite DARS coverage area to restore interrupted service. Even then, the system's mobile reception would fail at speeds in excess of 40 mph.

Significantly, this finding proves conclusively that the Commission erred in its earlier assumptions regarding the role of terrestrial gap-fillers. Specifically, the Commission had concluded "that one terrestrial repeater might provide sufficient gap-filling coverage for a satellite DARS system to reach the entire San Francisco area."[10] The CRC Report demonstrates conclusively that, if mobile reception is to be achieved, a significant number of additional gap-fillers will be required. Moreover, the CRC Report shows that using one high-powered gap-filler to restore urban reception creates a far greater area of interference beyond the range of the gap-filler's terrestrial coverage area.[11] The CRC Report also demonstrates that satellite coverage can be transparently supplemented with gap-fillers without interference, but only through the careful and elegant tailoring of the gap-filler's coverage and through the finely tuned use of guard interval duration.

B. The Commission Must Consider That the Inherent Spectral Characteristics of the S-band Will Significantly Impair the Delivery of Acceptable Satellite DARS Service to Users in Mobile and Urban Environments

A number of parties to this proceeding have expressed that there is little difference between

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[9] *See* CRC Report at pg. 33. *See also*, CRC Report Figure 5.9.

[10] Letter of Reed Hundt to the Hon. W. J. Tauzin, April 23, 1997 (enclosing replies to Scott Klug and Nathan Deal in conjunction with the House Telecommunications Subcommittee hearing on spectrum issues held on February 12, 1997).

[11] *See* CRC Report at pg. 33. *See also* CRC Report Figure 5.3.

the signal propagation characteristics of DARS at S-band (2310-2360 MHz) and, for example, L-band (1452 - 1492 MHz) frequencies. That opinion is apparently based upon a simple comparison of the attenuation associated with free-space propagation at these frequencies. As detailed in Section 4 of the CRC Report, a comparative evaluation of S-band frequency propagation for DARS is a far more complex analysis.

Specifically, Section 4 of the CRC Report examines factors including free-space propagation as well as absorption, diffraction, fading effects and location variability models in order to determine the level of signal impairment experienced at S-band frequencies. Significantly, the CRC Report finds that the operation of satellite DARS in the S-band will have a substantial negative impact upon the coverage characteristics of both the direct satellite signals and the signals of terrestrial gap-fillers compared to L-band frequencies. This signal degradation will result in the impairment of service to receivers located in both mobile and urban environments and, as outlined above, will require a greater reliance upon terrestrial gap-fillers.

Specifically, the CRC Report concludes that "sizable differences" (totaling 10 dB) exist in propagation between L-band and S-band. According to the Report, in the case of satellite propagation, there is a 4 dB disadvantage at S-band due to an increase in free-space loss. Additional losses result from increased absorption by trees, defraction over rooftops and increased reception variability resulting in approximately a 6 dB loss at S-band as compared with L-band. This impairment alone will significantly impact satellite designs, transmit power, system costs and system designs if adequate coverage is not to be compromised. In the case of terrestrial propagation, the CRC Report finds that various factors result in an approximate 10 dB penalty for reception from a typical terrestrial gap-filler. Again, this signal loss impacts overall system design, the number of gap-fillers required, and the overall cost of an S-band DARS system.

More critical, perhaps, is the relationship of the frequency band of operation to the effectiveness of particular DARS technologies designed to deal with channel impairments and multipath fading. Section 4 of the CRC Report describes applications of digital signal processing technologies that may be used to combat various channel impairment conditions prevalent in mobile reception environments. These include error detection and correction methods, robust digital modulation and adaptive mitigation techniques such as channel estimation and equalization as well as the use of multi-carrier modulation.

Using multi-carrier modulation techniques as a model, Section 5 of the CRC Report analyzes design tradeoffs of particular guard intervals used to avoid inter-symbol interference caused by Doppler spread in mobile reception. When applied to terrestrial gap-fillers, the Report shows a **570% increase** in the number of omnidirectional gap-fillers necessary for S-band DARS systems when compared to L-band systems.

Most importantly, however, is the Report's finding that S-band service can be restored through the extensive use of terrestrial gap-fillers, but the resulting service can only be maintained at speeds below about 40 miles per hours due to the modeled guard interval and the resultant Doppler spreading of the signal in an urban environment.[12/] This velocity limitation is unsuitable for maintaining continuity of service on urban highways.

[12/] CRC Report at § 5.2.2

The CRC Report finds that all the principles and limits described in the case of multi-carrier modulation also apply in the case of a single carrier per channel (SCPC) modulation scenario. Moreover, narrowband SCPC suffers S-band implementation penalties of decreased throughput, Doppler spread requiring three time the computing power in receivers, compared to L-band, and the inability to handle flat fading environments. Further, wideband SCPC systems, according to the CRC Report, cannot practically be deployed in conjunction with terrestrial on-channel gap-fillers at either band.[13/]

C. The CRC Report Findings Support the Conclusion that the Commission Must Adopt Rules Governing the Both Build-out of Terrestrial Transmitters and the Actual Performance and Coverage of Satellite DARS Licensees

The CRC Report indicates that rapid and extensive deployment of terrestrial gap-fillers is essential if the Commission's vision for DARS remains to provide CD quality, nationwide, continuous service to mobile, rural and urban listeners. The CRC Report further demonstrates the validity of CEMA's original concerns regarding the deployment of S-band DARS.

In light of the CRC Report and earlier CEMA technical findings, CEMA strongly urges the Commission to fulfill its obligations under Section 309(j) of the Communications Act "to . . . promote . . . the development and rapid deployment of new technologies, products and services for the benefit of the public," and implement reasonable coverage, quality and performance build out requirements necessary to achieve the seamless CD quality service that was originally promised. CEMA maintains

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[13/] The CRC Report discusses, in a technically comprehensive manner, the intrinsic limit in carrier frequency for mobile reception in a complex fading environment. These limits impact DARS implementation and are directly due to the frequency band of operation and the manner of digital modulation and coding employed. Section 7 of the CRC Report illustrates some of the tradeoffs concerning the complexity of satellite and receiver systems as a function of the DARS frequency used.

that the establishment of rules requiring the rapid and ample deployment of these gap-fillers is necessary to ensure the widespread commercial success of DARS as well as to prevent the warehousing of valuable spectrum in the event that the licensees are, within a reasonable period of time, unable to provide acceptable service to urban and mobile receivers Moreover, CEMA submits that in the absence of specific requirements, the licensees will resist bearing the costs associated with the nationwide urban deployment of a vast network of terrestrial gap-fillers. As the CRC Report demonstrates, however, the rapid deployment of this terrestrial network is absolutely essential to the practical and commercial success of satellite DARS.

CONCLUSION

As detailed in these Comments and the attached CRC Report, the build-out of terrestrial gap-fillers is critical to the widespread success of S-band satellite DARS systems. For the foregoing reasons, CEMA strongly urges the Commission to adopt reasonable requirements governing the build-out of terrestrial gap-fillers and the overall performance of satellite DARS systems -- particularly in urban and mobile environments.

Respectfully submitted,

The Consumers Electronics Manufacturers Association

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EXHIBIT 1

Communications Research Centre
Centre de recherches sur les communications

Analysis of the technical merits of terrestrial gap-fillers supplementing DAR satellite broadcasting in the L-band and S-band frequency range

(21 May 1997)

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Executive summary

This study analyzes the technical merits of terrestrial gap-fillers to supplement the coverage of satellite Digital Audio Radio Broadcast Service (DARS) and analyzes the impact of the system carrier frequency in the range covering L-band (1452-1492 MHz) and S-band (2310-2360 MHz) on the characteristics of such systems. This analysis was done in the context of the provision of a seamless coverage for satellite broadcasting of DARS as stated in the report presented to the FCC by the DARS Pioneer's Preference Review Panel.

This report discusses the various technologies and implementation means available in trying to achieve seamless coverage from a satellite and the effectiveness and relative complexity of the implementation of terrestrial gap-fillers to complement satellite DARS systems as well as the impact of the operating frequency, in the range of 1452 MHz to 2360 MHz, on the overall system complexity. Summary results of this analysis include:

1. Sizable differences exist in propagation between L-band and S-band. First, a 4 dB disadvantage at S-band exists due to an increase in free-space loss. This 4 dB disadvantage adds to other losses from absorption by trees, diffraction over rooftops in urban area reception, along with increased reception variability. These extra losses occur to different extent in the satellite and terrestrial cases. Taking all factors into consideration, approximately 6 dB higher satellite transmitter power may be needed at S-band as compared to L-band to provide the same DAR service availability. In the case of the terrestrial propagation, which will apply to reception from the terrestrial repeaters, beyond the 4 dB disadvantage at S-band due to augmentation in free-space loss, a further 3 dB fade margin has to be included due to absorption by trees and diffraction and an additional 3 dB margin is needed to secure a 95% coverage availability due to the increased field strength variability at S-band. This would translate in an increase in transmit power of some 10 dB for typical reception from the terrestrial gap-fillers.

2. Deploying on-channel terrestrial gap-fillers is considered to be the only effective way to provide seamless coverage for vehicular reception in all practical environments. Channel characteristics are examined and shown to consist, for the mobile environment, of flat fading (shadowing, normally modeled by a Log-normal distribution) and frequency selective fading (multipath, modeled by a Rayleigh statistical distribution). Although terrestrial repeaters allow for filling the satellite coverage gaps created by blockage due to the excess power available, this is done at the cost of creating an exacerbated multipath channel environment due to the presence of active echoes created by these gap-fillers. Error detection and correction methods, robust digital modulation and adaptive mitigation techniques such as channel estimation and equalization or multi-carrier modulation are examined to address these new demanding channel conditions.

3. In the case of the multi-carrier modulation, the relationship between the number of carriers, their spacing, symbol duration, guard interval duration and signal bandwidth is analyzed as to their effect on performance. The carrier spacing determines the impact of Doppler spread interference which is linearly related to the operating frequency and the vehicle speed. Models comparing L-band and S-band coverage show that a larger number of terrestrial repeaters is needed at S-band as compared to L-band to cover a given area while still allowing service to vehicles moving at speeds up to 80 km/h in urban environment.

4. Single carrier modulation systems (as proposed by satellite DARS applicants) must also use terrestrial gap-fillers to effectively compensate for shadowing by buildings in dense urban areas even in the case where satellite diversity is proposed. The presence of these gap-fillers makes the channel more difficult to correct because of the range of excess delays created by the presence of these active echoes. Channel equalization techniques need to be used to correct for the resulting frequency selective fading in the channel. Considerations of complexity and reasonable channel overhead dedicated for the training of these equalizers limit their applicability to narrowband systems (e.g., 200 kHz bandwidth).

5. The impact of the carrier frequency is examined for the hybrid satellite/terrestrial DARS operation. For the case of the multi-carrier modulation, values are given for parameters such as the distance allowed between repeaters and the expected attenuation on the terrestrial path. These parameters are related to the linear scaling of the guard interval with respect to frequency to keep a constant robustness of the system against Doppler spread. Coverage exercises have demonstrated that, when omnidirectional terrestrial repeaters are used, 15 of these repeaters are needed at L-band to augment the satellite coverage over a given service area whereas 85 would be required at S-band (resulting in a factor of 5.7 in number of repeaters between the two bands). When optimal directional terrestrial repeaters are used, their number can be reduced to 4 to cover the same area at L-band whereas 11 directional repeaters are needed at S-band (for a factor of 2.75 between the two bands).

6. A qualitative assessment of the various elements that affect DARS systems performance indicates appropriate frequency ranges that can be used for a hybrid satellite/terrestrial DARS system to provide seamless coverage to areas such as full CONUS down to ¼ CONUS. Figure 7.1 summarizes this discussion in a graphical form and illustrates some of the trade-offs concerning the complexity of satellite and receivers systems as a function of the carrier frequency. Due to the complexity of this discussion, it is clear that further investigation would be required to clarify and quantify these trade-offs.

1. Introduction

The Consumer Electronics Manufacturers Association, a sector of the Electronic Industries Association (EIA/CEMA), has requested a study to analyze the technical merits of terrestrial gap-fillers to supplement the coverage of a satellite Digital Audio Radio Broadcast Service (DARS) and to analyze the impact of the system carrier frequency in the range covering L-band (1452-1492 MHz) and S-band (2310-2360 MHz) on the characteristics of such systems.

The Communications Research Centre ("CRC") has developed, over the years, a wealth of expertise in the fields of propagation, satellite broadcasting as well as terrestrial broadcasting. In particular, it has developed expertise in the digital transmission of these broadcast signals in various channel environments. This report presents the findings related to the key technical merits of using terrestrial gap-fillers to complement satellite DARS systems and the impact of the operating frequency, in the range of 1452 MHz to 2360 MHz, on their effectiveness and on the relative complexity of their implementation.

Following are the results of an analysis done through a literature survey, application of scientific and technical knowledge, overview of results from studies previously conducted at CRC and gathering of opinions from CRC experts in the various related fields.

2. Background

This analysis was done at the request of EIA/CEMA to better understand the interrelationship of many parameters affecting deployment of terrestrial gap-fillers to complement satellite DARS. The FCC REPORT AND ORDER, MEMORANDUM OPINION AND ORDER AND FURTHER NOTICE OF PROPOSED RULEMAKING, IB Docket No. 95-91 solicits comments on DARS licensees use of gap-fillers to meet their service requirements.

Further, the provision of a seamless coverage for satellite broadcasting of DARS was stated in the report presented to the FCC by the satellite DARS Pioneer's Preference Review Panel [REP-96].

In this report, it was stated that:

> *"From a Listener's Standpoint, Radio Broadcasting Should be "Seamless"*
>
> *A radio broadcaster defines a coverage area for his broadcasts. Whether this be a small, local coverage area of tens of square miles, or all or most of the U.S., as in DARS proposals, or anything in between, the listeners of the broadcasts expect "seamless" reception. That is, an uninterrupted, high quality signal is expected everywhere within the coverage area as defined by the coverage contours for the particular service.*
>
> *Such an availability requirement within the broadcast coverage area is especially important for mobile reception. Listeners in cars and trucks do not want a signal dropping in and out within their driving locality."*

It was also stated that:

> *"After careful review of the designs presented in the documents, we find that "gap fillers" will be necessary to serve areas "seamlessly" for these designs. Once this is understood, the satellite signal delivery techniques described become no more than different ways of minimizing the local level of dependence on "gap fillers". In particular, the number and power levels required to combat the effects of building and foliage blockage will vary among the designs."*

The **need for seamless coverage** for DARS has been clearly established along with the **need for terrestrial gap-fillers** to actually implement it. The present report discusses the various technologies and implementation means available in trying to achieve this goal. There are a number of technical constraints that define the use and the extent of coverage of terrestrial gap-fillers supplementing satellite DARS. These are related to the frequency used by the service, the speed of the vehicle for which the service has to be provided, the complexity of the transmission infrastructure and the complexity of the technology to be used in the receivers.

3. Service objectives for DARS systems

3.1 High quality digital audio

The introduction of a new audio broadcasting service will be successful if consumers perceive an obvious advantage, be it in sound quality, in service availability, in the type of service offered, or in the cost. From the technical point of view, digital coding is necessary to bring CD or near CD audio quality to the consumer. As a matter of fact, digitization of radio broadcasting chains is now in an advanced state, in many cases leaving only the last link to the public, that is the exciter, RF amplification and emission elements, in analog form.

Advanced audio source coding is used to reduce the bit rate in an attempt to maximize the use of radio frequency spectrum for sound broadcasting. It has been established, through subjective assessment testing done through the EIA/CEMA DAR Subcommittee system tests, that bit rates in the range 160 kbit/s to 256 kbit/s are necessary to reproduce stereophonic audio quality equivalent to Compact Discs [EIA-95]. For this discussion, it will be assumed that 256 kbit/s is needed per radio program to provide one CD-Quality stereophonic program (224 kbit/s) along with some 32 kbit/s ancillary data services.

3.2 Vehicular and portable reception

Today, a large percentage of the audience for sound broadcasting is made of people in transit, in their car or in public transportation. Digital sound broadcasting is already available for fixed reception through cable and satellite distribution. The DAR service is therefore aimed at addressing predominantly the mobile and portable segment of the audience. In fact, if it was to address only fixed reception where antennas can be aimed once at the satellite, the use of higher frequency bands with the possibility of relying on more directive antennas at both transmit and receive ends, such as the DSR system in Germany [ITU-90a], would make for better use of the spectrum. The principal merit of L and S-bands is that omnidirectional antennas can be used at the reception, allowing mounting of simple non-tracking antennas on cars and use of portable and wearable (e.g., walkman) receivers.

3.3 High service availability

On the basis of previous work done on digital sound broadcasting, it is evident that a graceful failure in audio service performance is difficult to achieve with digital modulation. Effective channel coding and digital modulation are inherently designed to keep the Bit-Error-Rate (BER) below a threshold, beyond which the audio quality degrades rapidly. It was found, through the EIA/CEMA DAR Subcommittee laboratory tests [EIA-95], that only a small differential (in the order of a few dB's) in received power exists between perfect audio received quality and unusable service quality.

Due to the abrupt failure characteristic of digital modulation, it will be necessary to ensure that reception is more reliable than in the cases of conventional AM and FM services. This can be achieved with a proper level of excess field strength available throughout the service area, especially where signal fading is likely to occur. Unlike with conventional FM, where the service availability was set at 50% locations and 50% time, F(50,50), the availability of the new DARS service will be needed to be in the range of 90% to 99% of locations and time to compensate for the abrupt failure characteristic mentioned above.

In this work, the location availability will be assumed to be 95% for the purpose of the field strength propagation predictions. It is believed that, if multiple gap-fillers are used in a proper fashion to blanket a given area, the gain obtained by this transmit diversity will bring the actual service availability in the neighbourhood of 99%.

3.4 Seamless coverage

Adequate vehicular and portable reception is a fundamental requirement and because it is the most demanding receiving condition, the system has to be designed to meet this objective, considering that other modes of reception (i.e. fixed, transportable (boombox), wearable (walkman), etc.) should then be automatically covered. The mobile audience will expect uninterrupted high quality signal reception everywhere, within reasonable limits, in the service area. This "seamless" reception can be translated into a high service availability figure (e.g., 99% of locations and time) not only on highways but everywhere in the service area where mobile receivers are used.

3.5 Summary of service objectives:

The service objectives for a new DARS system can be summarized as follows:

- High quality audio and capability for new data services
- Vehicular and portable reception
- 99% service availability everywhere in the service area

In order to meet these objectives, the most advanced techniques must be employed in each and every component of the broadcasting system: audio coding, channel coding, modulation, transmission, receiver design, etc.

4. Description of the nature of the environment (satellite, terrestrial)

4.1 Introduction

In this section, we will attempt to describe the radio frequency environments to which the DARS receiver will be exposed. The most important factors will be explained and quantified. These include some specific propagation aspects and several key channel characteristics. This will lead to a study of the various techniques (modulation, coding, diversity, etc.) that must be used to mitigate the difficult channel conditions created by such environments in order to provide high service availability everywhere inside the target service area. Comparisons of the effectiveness of using these techniques in the frequency bands under study will be made. The emphasis will be put on vehicular reception as being the most demanding and complex reception environment. The use of a geostationary satellite is assumed throughout this study.

4.2 Hybrid satellite/terrestrial operation

An extensive description of the merits and limitations of what has been called the hybrid satellite/terrestrial operation [RAT-90] will be given throughout this report. The general concept behind this hybrid operation is that, although the satellite power is normally set, for practical reasons, to provide adequate service to rural and remote areas, terrestrial repeaters are used to extend the coverage to city and shadowed areas. This will ultimately result in a seamless coverage everywhere inside the target service area for vehicular reception. This hybrid coverage concept has the merit of translating a reasonably achievable predicted probability of coverage into a very high availability of service (e.g., 99%). At the same time, the use of terrestrial repeaters will also provide for this extra power that will allow reception with portable receivers inside buildings. Without terrestrial repeaters, this would only be possible through the use of an excessive power at the satellite (some 20 dB higher power) to compensate building penetration losses especially in areas where the satellite is seen at high elevation angles. The extension of service with terrestrial repeaters can, in fact, be done gradually by installing terrestrial re-transmitters progressively after the satellite has started providing service to the open areas.

The principle of operation of the hybrid concept is that the shadowed areas, especially in built-up environment, can be filled by the excess power that terrestrial repeaters can generate locally at the cost of making the channel multipath environment more difficult. It is based on the fact that new digital modulations have been designed to be able to cope with harsh channel multipath. Using on-channel terrestrial repeaters will produce additional active echoes at the receiver which could be taken advantage of as long as the active echoes generated by the terrestrial repeaters are within a certain excess delay range (i.e., inside the guard interval or inside the equalisation window). As will be seen later, this can be accomplished by proper localisation of the gap-fillers and restricting the power and/or the directivity of these gap-fillers to limit their coverage to a small area, thus ensuring that the satellite coverage, beyond this area, is not affected by the presence of destructive active echoes. With this simple system configuration, normal city coverage can be added to the satellite coverage in an elegant way.

The need and the various merits of the use of terrestrial gap-fillers are further described in Section 4.4.3.

4.3 Propagation aspects

The range of frequencies surveyed in this study for the DARS systems is between 1452 MHz and 2360 MHz. Two frequencies located at the center of the L- and S-bands will be taken to establish the frequency dependency of propagation; that is, 1472 MHz and 2335 MHz.

4.3.1 Free-space propagation and frequency dependency

The dependence of free-space basic transmission loss L_{bf} on frequency f (MHz) is given by

$$L_{bf} = 32.4 + 20\log f + 20\log d$$

where d is the distance in kilometers. The term $20\log f$ is different by **4.0 dB** for the two frequencies of interest and is caused by the reduction of the effective receiving antenna aperture with the increase in frequency. This 4 dB loss can, however, not be recovered by increasing antenna gain because of the need to keep the antenna pattern close to omnidirectional (to avoid the need for a tracking antenna on cars). Although broadcast reception can take place over a large range of heights above the ground, a receiving antenna height of 1.5 m is assumed in this section because this antenna height is appropriate for vehicle reception and that if coverage can be obtained at this height, it can also be obtained higher up.

4.3.2 Satellite propagation aspects

4.3.2.1 Absorption by trees

Depending on the distance between the receiving antenna (assumed close to the ground) and the nearest trees, radio waves may arrive by diffraction over the trees, or by passing through the trees. This section is concerned principally with the absorption of radio waves passing through trees. This is of concern where a roadway is lined by a row of trees, or in a residential area containing mature trees. For short paths through trees, the decay in received power is exponential with the distance d through which the wave must pass through the trees. An expression for this loss, due to Lagrone [LAG-77] is:

$$L = 0.00129 f^{0.77} d$$

An extensive study of the absorption of radio waves by trees in temperate climates was made later by Weissberger [WEI-82]. He quoted Lagrone and others, but proposed the following model based on data taken in a cottonwood forest in Colorado in the frequency range 230 MHz to 95 GHz:

$$L = 0.063 f^{0.284} d \qquad 2 < d < 14\text{m}$$

$$L = 0.187 f^{0.284} d^{0.588} \qquad 14 < d < 400\text{m}$$

The first formula will be applicable in the case of satellite reception. As a specific example, consider a distance of 14 m, and use Weissberger's formula at 1472 MHz and 2335 MHz. The results are 7.0 dB and 8.0 dB. Using Lagrone's formula, the numbers are 5.0 and 7.1 dB. So the difference with frequency is 1 or 2 dB. However, the numbers just given are average values in a stand of trees of the given thickness. The fades resulting from absorption by individual trees will be much greater.

4.3.2.2 Diffraction over rooftops

Diffraction over rooftops can be modeled as a function of building height and spacing by the methods of Maciel et al [MAC-93]. If the elevation angle becomes larger than about 2°, which will be the case for satellite reception, only one roof is expected to obstruct the wave, and we have simply a single knife-edge diffraction loss as explained in Section 4.3.3.1, with a frequency difference of 2 dB.

4.3.3 Terrestrial propagation aspects

4.3.3.1 Knife-edge effects

Many terrain obstructions can be modeled as knife edges, for example buildings, trees, and distinct ridges. The amplitude of the wave field in the shadow of such an object is proportional to the amplitude of the complementary Fresnel Integral F(x), which, well within the shadow region, is approximately given by 1/2x. The value of x, in turn, is proportional to $\sqrt{f}$. This means that received power is proportional to 1/f, and a knife-edge obstruction adds a term 10 log f to the path loss, giving 2.0 dB more received power at 1472 MHz than at 2335 MHz.

4.3.3.2 Diffraction over terrain

Longley-Rice

A widely used site-general model for diffraction over terrain is the Longley-Rice model, or ITS Irregular Terrain Model (in the area prediction mode), the most recent version of which is described by Hufford *et al* [HUF-82]. The terrain is assumed to be generally uncluttered. A parameter to be set is the interdecile height variation Δh of the terrain. Hufford suggests 90m as a representative value, and ITU-R Recommendation 370 [ITU-86a] suggests 50m. The latter value is perhaps more representative of populated areas, and is used here. The results presented below are sample runs at the two frequencies of interest, in which the transmitter is assumed to be carefully sited and the receiver randomly sited. The numbers given are path loss (dB) in excess of free-space loss.

Base station height = 100m Mobile station height = 1.5m Δh = 50m 50% time 50% locations

Distance (km):	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
2335 MHz	4.0	11.1	18.0	24.8	31.4	37.3	43.1	49.1	55.1	59.3 dB
1472 MHz	6.2	12.7	19.0	25.4	31.2	36.5	41.8	47.0	52.4	57.8 dB
difference	**-2.2**	**-1.6**	**-1.0**	**-0.6**	**0.2**	**0.8**	**1.3**	**2.1**	**2.7**	**1.5 dB**

The inference from this model is that the diffraction loss due to uncluttered irregular terrain does not change by more than about 2 dB between the frequencies of interest. The reason for the negative differences at short ranges is presumably that in the physical model used, the first Fresnel ellipsoid is only partly obstructed on the shorter paths, and as the ellipsoid becomes narrower at the higher frequency, it becomes less obstructed.

ITU-R Recommendation 1146

The third model is the entirely empirical model contained in ITU-R Recommendation 1146 [ITU-95a]. In this model, for receiver (or mobile) heights above the clutter, the path loss increases with frequency by values between 0.7 and 1.8 dB. Recommendation 1146 also has a correction for lower antenna heights, which at 1.5m gives, according to the type of clutter:

	Rural	**Suburban**	**Urban/Wooded**	**Dense Urban**
2335 MHz	19.7	27.2	37.5	43.0
1472 MHz	18.6	22.9	31.0	36.5
difference	**1.1**	**4.3**	**6.5**	**6.5**

That is, the attenuation due to the receiving antenna being below the clutter and close to the ground increases with frequency by values between 4.3 and 6.5 dB in built-up or wooded areas.

4.3.4 Diffraction around buildings

In a theoretical estimate, there are two kinds of paths to consider, diffraction over rooftops, and diffraction around vertical walls.

4.3.4.1 Many knife edges

Diffraction over rooftops can be modeled as a function of building height and spacing by the methods of Maciel *et al* [MAC-93]. There are two steps in the process. One is the propagation of the wave from the transmitter over many rooftops, and the other is the subsequent diffraction of the wave down to street level. Taking the diffraction down to street level first, this is just a single-knife-edge calculation, and the variation of excess path loss with frequency is 10 log f, as discussed in section 4.3.3.1. The other step to be considered is propagation over many rooftops. If the wavelength is small compared to the distance, the excess path loss is proportional to -9 log f. As with short paths in the Longley-Rice model, the narrower Fresnel ellipsoid associated with a higher frequency is less obstructed. This almost cancels the variation in the other term, leaving a difference of only 0.2 dB at the two frequencies. On the other hand, if the elevation angle becomes larger than about 2°, the other roofs no longer obstruct the wave, and we have simply a single knife-edge diffraction loss, with a frequency difference of 2 dB, as discussed already. So in this model, the difference in excess path loss between the frequencies of interest can be expected to be between 0.2 and 2 dB.

4.3.4.2 Diffraction around buildings

Diffraction around the corners of buildings is a form of wedge diffraction. The dominant term is a knife-edge diffraction term, and a frequency difference of 2 dB can be expected. Successive diffractions around two corners will give 4 dB, but the amplitude of double-diffracted waves is expected to be low compared to that of reflected waves.

4.3.4.3 Hata's empirical equations

Propagation in urban areas can be modeled empirically as well, and a very popular method of doing this is by using Hata's [HAT-80] equations, which are based on a massive set of measurements by Okumura et al [OKU-68]. In these, the frequency variation is 26.16 log f. When the 20 log f of free-space variation is removed from this, the frequency variation of excess loss is 6.16 log f. At the two frequencies of interest, the difference is 1.23 dB. There is also a frequency term in the mobile antenna-height correction, but at a mobile-antenna height of 1.5m this vanishes. On the other hand, a version of the Hata equation as modified by COST 231 (cited by Doble [DOB-96]) specifically for the frequency range 1500 to 2000 MHz has a frequency variation 33.9 log f leaving 13.9 log f for excess loss. At the two frequencies of interest, the difference is 2.8 dB.

4.3.5 Absorption by trees

This topic was covered in Section 4.3.2.1 above dealing with satellite propagation aspects. The difference in absorption between the two frequencies may be more pronounced in the terrestrial case, due to the lower angles of elevation and consequent longer paths through trees in many cases. For example, if the distance traversed through trees is 100 m, Weissberger's formula predicts losses of 22.2 dB and 25.3 dB for L-band and S-band respectively, or a difference of about 3 dB.

4.3.6 Location variability distribution

In rural areas, for all paths of a given length, the standard deviation σ_L of the location variability distribution may be estimated for $\Delta h/\lambda < 3000$ as

$$\sigma_L = 6 + 0.69\left(\tfrac{\Delta h}{\lambda}\right)^{1/2} - 0.0063\left(\tfrac{\Delta h}{\lambda}\right) \qquad \text{dB}$$

and for $\Delta h/\lambda > 3000$ as $\sigma_L = 25$ dB,

where $\lambda = 300/f$, and f is measured in megahertz, and where Δh is the interdecile height variation in the distance range of 10 to 50 km from the transmitter. This formula is equation (11) of CCIR Report 567-4 [ITU-90d], pointed to by ITU-R Recommendation 529-1[ITU-94]. It comes from Longley [LON-76], and describes mainly the effects of hilly terrain, rather than trees or buildings. For $\Delta h = 50$ m, the argument $\Delta h/\lambda$ is 245 and 389 for the two frequencies of interest. This gives σ_L = 15.26 dB and 17.16 dB for the two frequencies.

In flat urban areas, the standard deviation over a large area may be estimated from Figure 39 of Okumura *et al* [OKU-68]. This represents data for an area 2 km in radius, much smaller than for the last equation. The results are σ_L = 7.05 dB and 8.93 dB for the two frequencies of interest. The same diagram gives a curve for a suburban area and rolling hilly terrain, again for an area 2 km in radius. This curve gives σ_L = 7.68 dB and 9.62 dB for the two frequencies of interest. For both the Longley and Okumura data, the variability is for all paths of a given length, not the variability over a small area.

The location variability is important if it is required to obtain coverage over a large percentage of a service area. For a log-normal distribution, the required margins are as follows:

Percentage locations:	**50%**	**84%**	**90%**	**95%**	**98%**
margin, σ_L = 7.05 dB	0	7.05	9.04	11.6	14.5 dB
margin, σ_L = 8.93 dB	0	8.93	11.45	14.7	18.3 dB
difference for flat urban area (2km)	**0**	**1.9**	**2.4**	**3.1**	**3.8 dB**
margin, σ_L = 7.68 dB	0	7.68	9.85	12.63	15.8 dB
margin, σ_L = 9.62 dB	0	9.62	12.33	15.82	19.8 dB
difference for suburbs, hills (2 km)	**0**	**2**	**2.5**	**3.2**	**4.0 dB**
margin, σ_L = 15.26 dB	0	15.26	19.56	25.10	31.3 dB
margin, σ_L = 17.16 dB	0	17.16	22.00	28.23	35.2 dB
difference for hills (10 - 50 km)	**0**	**1.9**	**2.4**	**3.1**	**3.9 dB**

Note that in this last case, the margins seem very high, but the total margins cited would only be required if a circular coverage area were specified for a single transmitter.

The specific result of interest here is that for 95% coverage at a given distance, the margin required is greater at 2335 MHz than at 1472 MHz by some 3 dB.

4.3.7 Summary of Propagation Aspects

A significant difference between L-band and S-band is the 4 dB higher free-space transmission loss in the latter band, due to the smaller effective receiving antenna aperture. This loss is over and above the losses described below. Other losses which can be expected to be higher at S-band include those from absorption by trees (typically 1 to 2 dB higher in the satellite case and some 3 dB in the terrestrial case) and diffraction over rooftops (up to 2 dB higher, particularly in the satellite case where a single diffraction is likely). In urban areas, formulas based upon the work of Okumura and Hata predict that the excess path loss (versus free space) will be from 1 to 3 dB greater in the higher band. In irregular rural terrain, the predictions of the Longley-Rice model do not clearly favor one over the other. However, the empirical model contained in ITU-R Recommendation 1146 does predict greater losses at S-band in all environments, the differences ranging from 1 dB in rural areas to 6.5 dB in urban and wooded areas for a 1.5 m receiving antenna height. Also of interest is the variability of the received signal levels over large areas, since this has a significant effect on overall coverage. The Okumura models predict higher standard deviations at S-band than L-band in all environments. For example, if 95% coverage is desired at a given distance from the transmitter, it is predicted that about 3 dB higher margin will be required at S-band.

Taking all factors into consideration, one can conclude that approximately 6 dB higher satellite transmitter power may be needed at S-band as compared to L-band and a further 4 dB higher transmit power may be needed in the terrestrial case, for a total of 10 dB for typical receiving situations with 95% coverage availability to cover for the extra fading through trees and the increased variability of the signal.

4.4 Channel characteristics

4.4.1 The satellite channel characteristics

All satellite DARS experiments so far confirm that mobile reception of a satellite service is a sizable challenge. Unlike terrestrial installations, satellites have a much more important limitation in terms of the power they can transmit. It is common practice to set the **power on the satellite** such that it produces a weak signal on the surface of the earth, although sufficient to secure operation of receivers a few dB's above operation threshold when proper receive antennas such as satellite dishes are assumed. In a mobile environment the **receive antenna must be omnidirectional**, small and inexpensive. The expectations in terms of receiver antenna gain cannot exceed 5 to 6 dB in the case of car reception unless a rather complex and expensive antenna providing more directivity and gain is used along with a tracking system. Such a tracking system could only be dispensed with in the case of a satellite close to the local zenith (within the beamwidth of the receive antenna).

As an example, let's consider AMSC, a mobile communications satellite able to support 3200 telephony channels. The AMSC satellite is among the most powerful satellites flown operating in L or S-band and it uses advanced technologies such as a deployable 6 m diameter antenna and a 600 W solid state amplifier. Still, the mobile receiver is expected to be equipped with an antenna providing 9 to 13 dBi gain. In a typical satellite broadcasting system for vehicular reception, the onus will be on the satellite side to provide enough power to compensate for the low antenna gain possible at the receiver due to directivity, size and cost constraints and still allow for some fade margin in the link budget.

The next question is how much **fade margin** must be provided?. How much is needed to ensure adequate reception everywhere within the service contour? Obstruction (or **blockage**) is the first factor to be considered. The severity of the fades caused by obstructions depends on the nature of the obstruction. Blockage is usually caused by trees, buildings, road signs, overpasses, bridges, etc. Successful satellite experiments at L-band have revealed that 2 to 3 dB fade margin is sufficient to provide good reception as long as the receiver is in line-of-sight with the satellite [FOO-96]. Unfortunately, the many obstacles lining the road constantly obstruct the line-of-sight, creating fades in the range of 5 to 20 dB. Fade margins of that magnitude are not practical for a satellite system because of power limitations. The reception is affected by these deep fades and the service availability decreases accordingly. It is therefore accepted that reliable reception from the satellite will be possible only where line-of-sight conditions exist. This is a very limiting condition which does not suit well a digital sound broadcasting service aimed at minimizing system outage in vehicular reception and provide seamless coverage.

The **duration** of the signal fades must also be considered in the case of vehicular reception. Efficient techniques such as time-interleaving exist to compensate for relatively short fades. Errors can then be detected and corrected. However, in suburban and urban areas, the fade duration can exceed the capabilities of typical time interleaving techniques when vehicles have to progress at slow speed. This is even more acute in the case of portable (wearable) receivers (i.e., walkman). The densely built-up urban areas represent the most demanding environment because of the extent of blockage and the variability of the traffic speed which can produce long fade durations.

The **magnitude** of the fade is, in most cases, a function of the elevation angle to the satellite. Typical values of elevation angles for receivers located in the continental USA (CONUS), and pointing at a geostationary satellite range from 55° (latitude = 27°, e.g., Tampa) to 30° (latitude = 47°, e.g., Seattle) or even less depending on the orbital location of the satellite. Goldhirsh and Vogel [GOL-92] have developed an empirical model that predicts that, while driving on a highway or a rural road, 1% of the distance traveled will be characterized by fades greater than 10 dB at 55° and 21 dB at 30°. The dominant sources of shadowing in this case are the roadside tree canopies. The effect of the elevation angle on the magnitude of the fade is significant, 9 dB of difference between 30° and 55°. This leads to the consideration of another major factor: the **type of environment** and terrain in which the receiver is operating. The intensity, occurrence and duration of blockage increase as the receiver moves from an open area to suburban area with more trees and buildings and finally into a dense urban area with high-rise buildings near the street. Once in a dense urban area, some of the fades are so deep (>20 dB) and building height is so large that elevation angle has no significant effect except when it reaches values of the order of 80° and above.

Table 4.1 below illustrates the relationship between some of the factors mentioned above, namely the fade magnitude or depth, the type of environment and the elevation angle. It summarizes the results of a satellite field trial at L-band done in Australia, in 1996 [FOO-96]. A carrier wave signal was transmitted at L-band by a satellite and measurements were carried out in two cities to investigate two different elevation angles, 33° and 51°, values that correspond to the domain of interest for the continental USA. Table 4.1 shows the magnitude of the fades encountered and their respective probability of occurrence by a mobile receiver in various parts of the two cities investigated.